Sources of Time Synchronization Error in IEEE 802.1AS

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Introduction

- This presentation provides
  - A summary of the sources of time synchronization error
  - An analysis of the time synchronization error due to oscillator frequency variation
- This was requested in the April 23, 2007 AVB timing call
- Note that both constant and variable error sources are listed (i.e., constant and variable in time)
  - Variable sources impact both time synchronization and steady-state jitter and wander
  - Constant sources impact time synchronization, but not steady-state jitter and wander

Summary of Sources of Time Synch Error - 1

❑PHY latency asymmetry

- May have constant and variable components, depending on implementation
- IEEE 802.3 specifies maximum transmit and receive PHY latencies, for the various PHYs
- These are summarized on slide 7 of http://www.ieee802.org/1/files/public/docs2006/as-cavendish-TimeSync802-3-060731.pdf
- 1000BASE-T
  - Maximum channel skew (cable delay asymmetry) of 50 ns (clause 40.7.4.2)
  - 84 ns transmit; 244 ns receive (table 40-14)
  - The above reference (Cavendish) adds 8 ns of latency to each direction
- 100BASE-X
  - Maximum cable delay asymmetry not given; http://en.wikipedia.org/wiki/Copper_cable_certification#Delay_Skew cites 25 – 50 ns as range
  - 140 ns transmit; 320 ns receive (table 24-3)
  - The above reference (Cavendish) adds 8 ns of latency to each direction

❑Phase measurement granularity

- Phase measurement granularity is 40 ns (assuming 25 MHz oscillator)

Summary of Sources of Time Synch Error - 2

- Oscillator frequency variation (frequency stability)
  - Random phase noise
  - Aging
  - Temperature variation
    - Digikey (http://www.digikey.com) gives temperature dependence of frequency offset for inexpensive quartz oscillator
    - $y(T) = (0.04 \text{ ppm}) * (T - T_0)^2$
      - T = temperature in °C
      - y = frequency offset in ppm
      - T_0 = 25 °C
- Frequency measurement granularity
  - Depends on number of bits of accuracy in frequency offset computation
  - Eg., with 32 bits, the frequency offset measurement error due to this effect is approximately 2.3×10^{-10}

Time Synch Error due to Oscillator Frequency Variation - 1

- In the most recent AVB timing call (23 April 2007) and the most recent AVB call (25 April 2007), there were discussions of time synchronization error due to oscillator frequency variation due to temperature during transients (e.g., startup)
- Data provided in http://www.ieee802.org/1/files/public/docs2007/as-harrison-startupdrift-0207.pdf showed drifts as large as approximately 0.1 ppm/s for startup of a wireless router that contained a 25 MHz oscillator
- In the calls, there was interest in looking at the effect of a maximum drift of 1 ppm/s
- Note that the maximum frequency offset is ±100 ppm

Time Synch Error due to Oscillator Frequency Variation - 2

- We can consider a sinusoidal frequency variation with zero-to-peak amplitude of 100 ppm and frequency such that the maximum drift rate is 1 ppm/s

$$y(t) = A \sin \Omega t$$

A = 100 ppm = 10^{-4}

Ω= 0.01 rad/s

With these values, we obtain

$$y'(t) = A\Omega \sin \Omega t$$

The maximum value of $y'(t)$ is $A\Omega$ = (100 ppm)(0.01 rad/s) = 1 ppm/s

Time Synch Error due to Oscillator Frequency Variation - 3

- We may now consider applying this sinusoidal frequency variation to the first node after the grandmaster in a chain of TCs, and apply the results in http://www.ieee802.org/1/files/public/docs2007/as-garner-protocol-synton-chain-freq-offset-accum-0307.pdf
- Eq (4-5) in this reference gives the result for phase accumulation due to a frequency offset perturbation applied at the first node after the grandmaster

$$\left|\phi_{m,n}\right|_{\max} = AT_r \cdot \left\| \left[\left(1 + \frac{T_r}{T_I} - \frac{T_r}{T_I} e^{-j\omega} \right)^{m-2} - 1 \right] \right\|$$

A = frequency offset amplitude = 100 ppm = 10^{-4}

T_r = residence time = 0.01 s (10 ms (sync interval in worst case))

T_I = frequency update interval = 0.1 s (100 ms)

ω= discrete frequency = ΩT_I = (0.01 rad/s)(0.1 s) = 0.001 rad

m = number of hops

Time Synch Error due to Oscillator Frequency Variation - 4

- Since ω is small, we may approximate the above expression to first order in ω to obtain

$$
\begin{aligned}
\left|\phi_{m,n}\right|_{\max} &= AT_r \cdot \left\| \left[\left(1 + \frac{T_r}{T_I} - \frac{T_r}{T_I} e^{-j\omega} \right)^{m-2} - 1 \right] \right\| \\
&\cong AT_r \left\| \left[\left(1 + \frac{T_r}{T_I} - \frac{T_r}{T_I} (1 - j\omega) \right)^{m-2} - 1 \right] \right\| \\
&\cong AT_r \left\| \left[\left(1 + \frac{T_r}{T_I} j\omega \right)^{m-2} - 1 \right] \right\| \\
&\cong AT_r \left\| \left[(m-2) \frac{T_r}{T_I} j\omega \right] \right\| = AT_r^2 (m-2)\omega / T_I \\
&= AT_r^2 \Omega (m-2) \\
&= (10^{-4})(0.01\,\mathrm{s})^2 (0.01\,\mathrm{rad/s})(7-2) \\
&= 5 \times 10^{-10}\,\mathrm{s} = 0.5\,\mathrm{ns}
\end{aligned}
$$

Time Synch Error due to Oscillator Frequency Variation - 4

- The effect of the oscillator frequency variation is very small because the frequency of the variation is very small (0.01 rad/s, or 1.6 mHz) relative to the frequency update rate (10 Hz)
- Note that if we use the result for the split syntonization scheme (Eq. (6-8) in http://www.ieee802.org/1/files/public/docs2007/as-garner-protocol-synton-chain-freq-offset-accum-0307.pdf), we obtain the same result if we expand the expression to first order in ω